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UNU-MERIT Working Paper Series

#2014-046

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UNU-MERIT Working Papers

ISSN 1871-9872

Maastricht Economic and social Research Institute on Innovation and Technology, UNU-MERIT

Maastricht Graduate School of Governance MGSoG

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Successive Leadership Changes in the Regional Jet Industry

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May 2014

Abstract

This study examines leadership dynamics in the regional jet manufacturing industry from the 1980s onwards. With the help of leading products (aircraft or aircraft family), British Aerospace (BAe), Fokker, Bombardier and Embraer consecutively took the leadership in terms of new deliveries. In order to understand the co-evolution of demand for aircraft, technology and industrial structure, the paper applies a framework for innovation system dynamics that investigates in detail the preconditions for growth, windows of opportunity and strategic response of firms. In the first major leadership change, BAe and Fokker lost their leadership to Bombardier, which was the first to respond to a combination of windows of opportunity (more efficient jet engine technology, cheaper oil prices, market liberalization and the expansion of regional services boosted by the introduction of scope clauses) that created a niche for the 50-seat market. Bombardier's radical innovation, the business-jet based CRJ200 became the leading product of the 1990s. A second leadership change occurred in 2005, as new demand and regulatory windows (increasing oil prices, more competitive market, fluctuating economy, relaxing scope clauses) opened new opportunities for the 70-120 market segment to the detriment of both the 50-seat regional and 150-seat large civil jet markets. The Brazilian Embraer, with its already proven design, manufacturing and marketing capabilities in the regional jet industry was the first to make a strategic move and introduce a new product line, the ERJ-170/190 specifically intended for this market. The fate of failed challengers and past leaders points to the importance of preconditions, timing of windows of opportunity, speedy strategic response by companies and a proper evaluation of future demand. The long lead time between development and entry into serial production necessitates favourable demand windows both during the development and the serial production phases in order to turn a new product into a leading product, thus timing of response was found to be critical not only for gaining leadership, but also for staying in the market and recovering sunk costs.

Keywords: industrial dynamics; leadership change; sectoral innovation systems; aircraft industry; regional jets; windows of opportunity;

JEL Classification: F23, L21, L22, L62, O14, O32, O38

Acknowledgement: This paper benefitted from comments and suggestions by Profs. Keun Lee, Franco Malerba and participants of the 2013 June Milan and 2014 May Seoul Workshops on Changes in Industrial Leadership and Catch-up Cycles, which are gratefully acknowledged.

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1. Introduction

Most of the studies on the dynamics of the aircraft manufacturing industry have concentrated on the companies that produce large civil aircraft (Moran and Mowery, 1991; Golich, 1992; Frenken and Leydesdorff, 2000; Pavcik, 2004; Kechidi, 2013, Prencipe, 2013). Whereas the historical competition of a handful of large companies has crystallized into the Boeing-Airbus duopoly by the turn of the millennium, the regional jet market continues to witness turmoil, as it has for the last four decades. A multitude of companies from around the world have or had stakes in this market which is intentionally eluded by Boeing and Airbus, including those with a long tradition of constructing aircraft such as Fokker, Canadair or British Aerospace and its predecessor Hawker Siddeley, newcomers such as the Brazilian Embraer or the Chinese Comac that aims to use this as a stepping stone for entering the large civil aircraft market. Many of these companies emerged as the largest producer for some years, but none of them managed to sustain their top positions for as long as a decade. The purpose of this study is to explore the evolution of this industry and identify the key driving forces behind changing leadership in the regional jet segment.

The focus of this study is the regional jet segment of the commercial aircraft manufacturing industry. Regional jets are defined as aircraft powered by turbofan (jet) engine with an average seating capacity of 50 seats (ranging typically between 20 and 110) and an operational range of up to 2000-2500 nautical miles. While their size, range and operational costs at shorter distances distinguish regional jets from large civil aircraft, they all share a lot of commonalities in terms of their technological modularity or from an operational point of view. In fact, the upper boundary of the regional segment is rather elusive, and the smallest members of the Boeing 737 or Airbus 320 families are highly similar to the largest of Embraer's E-Jets or Bombardier's C-Series. At the other end, not their seating capacity, but their propulsion distinguishes regional jets from turboprop-powered commuter planes. These turboprops may be more economical to operate at short distances than regional jets, but are noisier for passengers and are more limited in terms of cruising altitude, speed and range. The term regional jets have gained familiarity in the 1980s. Based on the definition applied, many smaller jet aircraft of the preceding decades would qualify as regional jets. However, aircraft such as the Sud Aviation SE-120 *Caravelle,* the British Aircraft Corporation BAC-111 or the DC-9-10 do not qualify as regional jets as they are understood today as they served different markets (connecting main airports rather than extending service to regional airports) and their less efficient engines have not allowed the same economical operation on shorter routes. Before the beginning of the 1980s, typically turboprop commuter aircraft served regional routes. Finally, it is noteworthy that regional jets show the highest commonalities to larger executive or business jets. While there is little difference in terms of technological performance characteristics of such aircraft, the nature of customers and demand patterns differ more. In sum, even if the regional jet segment is distinct from other segments of the commercial aircraft industry, given all these proximities, producers can relatively easily benefit from diversification.

The evolution of the regional jet industry can be discussed in different dimensions and levels. One dimension is focusing on the demand side, on the factors influencing future demand, and the characteristics of users; here, recent developments in the Asia-Pacific region have received interest in the media. Another point of entry is focusing on the supply side and examining the changing characteristics of competition and competitiveness. This study makes the point that leadership dynamics can only be understood and explained by looking simultaneously at the co-evolution of technology, innovative and productive activities of firms, and the aircraft market in combination with the broader macro-economic and political environment. In the end, competitiveness in the global aircraft industry in general is affected by many interrelated factors: by the availability of capital, thus directly or indirectly affected by financial markets, access to risk-sharing partners, government support; by the design capabilities and production capacity, by internal organization of corporations and market and by the characteristics of a given aircraft programme, such as price and operation costs, which can benefit from commonality with other models and maintenance arrangements (USITC, 1998).

2. Leadership changes

Leadership of an aircraft manufacturing company can be measured in different ways, for instance, in terms of turnover or productivity of the company, number and value of new orders or aircraft deliveries. It is very difficult, if not impossible, to properly single out revenue and employment data that concerns the activities of a company related to regional jets, given the fact that this segment is not the only business activity of any of the companies we examined. Even if aircraft manufacturing can be distinguished from others, most companies had stakes in the defence or in the corporate jet industry. It is equally difficult to obtain data on the value of new aircraft deliveries, as deals typically remain secret and it is assumed that airlines with large orders receive significant discounts from list prices. New aircraft deliveries is accepted in the literature as a good way to measure the success of a company on the market (only aircraft with a dedicated buyer are manufactured), and also reflects actual demand better than new orders, which can be cancelled (Heerkens et al, 2010).

The analysis of historical evidence in this study will be based on publicly available primary and secondary sources, such as company annual reports, delivery statistics from Airlinerlist.com newspapers and trade literature (various editions of *Flight International*, *Aviation Today*, *Aviation Week and Space Technology* and *Financial Times*). We have found some differences between these sources on the quantity of aircraft delivered in a year, typically due to the mismatch between the financial and calendar years, but none that would significantly affect leadership change.

In the 1970s and 1980s, the makers of regional jets were primarily European companies. British Aerospace (BAe), a public company created in the United Kingdom (UK) in 1977 in a wave of consolidation through the merger of the British Aircraft Company, Hawker Siddeley and Scottish Aviation, was active in the defence as well as in the commercial markets. Re-launching Hawker Siddeley's "146", a four-engine, 109-seater jet, BAe expected to profit from the deregulation of the US airline business, from cheaper operations due to more efficient engine designs and from public demand for more modern and more quiet engines.[2] The BAe-146 aircraft family that came in three sizes (-100/200/300) gained success in the US early on, and by 1985 BAe became the largest producer of jet aircraft in the 70/110-seat segment, overtaking Fokker's outgoing F-28 *Fellowship* model in the number of deliveries. The production of BAe-146 peaked in 1990, and BAe experienced a severe crisis in 1992, prompting a write-down of its assets and a 47 per cent cut in its workforce. The production of the updated versions of the BAe-146 was reorganized under Avro International, and as a result, the RJ-70/85/100 extended the production run of the British regional jets until 2001. The then owner of the Avro jets, BAE Systems decided to stop the planned upgrade of the RJ family by considering it not viable and thus ending commercial aircraft assembly in the UK.

The other European regional jet maker was the Dutch company Fokker. Even if experts debate whether its F-28 *Fellowship* was an early regional jet, the model was rather successful and produced from the late 1960s until the mid-1980s and Fokker used this for upgrading into the larger (100-120 seat) and more efficient F-100 regional twin-jet. However, by the time the serial production of the F-100 began, the market leader was BAe, as Fokker was nearing insolvency in 1987 due to the costs of simultaneous upgrade of two of its design

[2] "Britain's First New Airliner for 18 Years", *New Scientist*, 24 June 1982

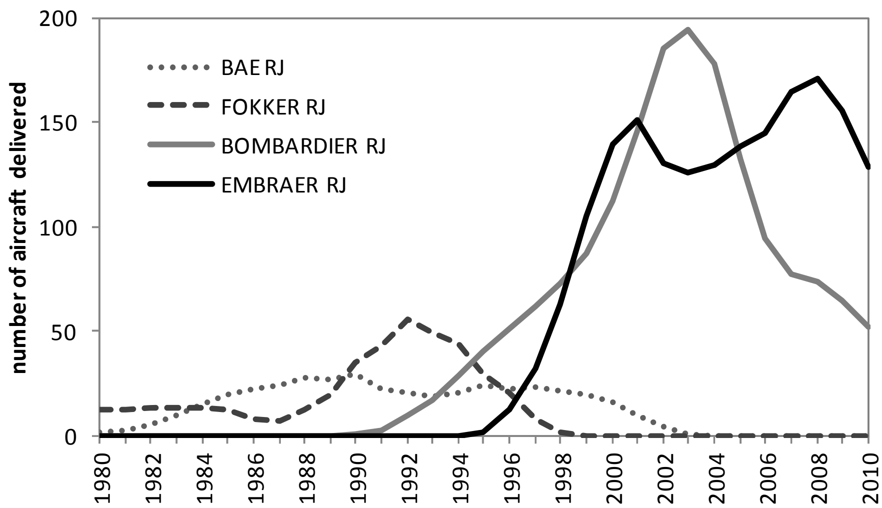
(a turboprop commuter along the F-100) and was saved by a government bail-out. The very strong initial sales of the F-100 between 1989 and 1993, and the efforts to launch the F-70, a shorter version of the plane with 79 seats, made Fokker the market leader in regional jets once again by 1991. However, Fokker's prices were too high in the competition from new producers outside Europe. With the Dutch government reluctant to intervene again, after a failed partnership attempt with the also troubled German aerospace company DASA, Fokker announced bankruptcy in 1996, ending the production of regional jets.

Neither of the two incumbent European companies could sustain their leadership in regional jets with the arrival of a challenger from Canada. Bombardier, a transport equipment manufacturing company (with products ranging from snow mobiles to locomotives, or light rail transit) entered the aircraft industry through the acquisition of a number of companies it successfully reorganized (including Canadair, Short Brothers, Learjet and de Havilland). Bombardier very successfully transformed a business jet design into the 50-seater CRJ100/200 Canadian Regional Jet. The CRJ family was subsequently extended by the stretched CRJ700/900/1000 versions, seating up to a hundred passengers. Bombardier achieved historically unprecedented delivery rates in the regional jet segment with its Canadian Regional Jet family, of which, in total, it has produced over 1,700 aircraft.

Initially, Bombardier could defend its leadership in the 50-70 seat market against the challenge from the emerging Embraer, the Brazilian competitor with experience in turboprop commuter that launched its ERJ-145 regional jet following its privatization in 1994. Embraer's 50-seater ERJ-145 was complemented by even smaller regional jets, the ERJ-135 and -140 with 37 and 44 seats respectively that became very successful at the global markets, especially in the United States, nearing the production rate of Bombardier. In the early 2000s, Embraer launched a new design, the larger E-Jet family (ERJ-170/190 models) in effect addressing the 70-120 seat market with economic solutions. At the same time, the production of Bombardier's CRJ product line peaked in the early 2000s, as the company was hesitant to launch a radically new design for the above-100-seat market. This delay appears to have cost Bombardier the leadership in regional jets in favour of the Brazilian company.

The changes in leadership (as measured by the number of deliveries) in the regional jet industry that took place between 1980 and 2010 and which are in the focus of this paper, are shown in Figure 1.

Figure 1 Regional Jet Deliveries, 3-year moving average, 1980-2010



Note: Delivery dates were obtained from the published lists of www.airlinerlist.com (retrieved: June 2012), the accuracy of which could only be verified for Bombardier and Embraer in the respective Annual Reports. Business jets, and other products of the respective manufacturers are not counted. The data includes the following products: British Aerospace RJ: BAC-111, BAe-146-100, -200 and -300 series as well as RJ-70, -85 and -100; Fokker: F-28, F-70 and -100; Bombardier: CRJ100, -200, -700, -900 and 1000; Embraer: ERJ-135, -140, -145, -170, -175, -190 and -195. A 3-year moving average was applied in order to smoothen any discrepancy between production and delivery years.

The central questions addressed by the study are the following: what windows of opportunity and what strategic response of companies facilitated these leadership changes? What other institutional factors supported the catch-up and competitiveness gain of the newly emerging leaders?

The research builds on three main strands of neo-Schumpeterian literature. First, on the literature that discusses the role of sectoral innovation systems as a source of industrial competitiveness in a leader as well as in a latecomer context (Malerba 2004; Mowery and Nelson 1999; Malerba and Mani 2009). It is argued that none of the three companies were new entrants to the industry at the time they succeeded in gaining leadership. Even Embraer, the relative latecomer, had already accumulated sufficient technological, production and marketing capabilities with related products that allowed it to make a strategic shift. The successful design and marketing of new products owe much to the companies' ability to build on and renew already existing technological and management capabilities, as well as to various modes of intervention by their host governments. All firms' success relied to some degree on an existing sectoral innovation system in which a supportive government played a key role. The growth momentum coincided with an institutional change within the sectoral innovation system. To explain growth spurts, a second strand of literature is considered which discusses discontinuities and the sources of dynamism in the co-evolution of industries and innovation systems (i.e., Abernathy and Utterback 1979; Tushman and Anderson, 1986; Klepper 1996; Galli and Teubal 2002, Lee and von Tunzelmann, 2005, Vertesy and Szirmai, 2010). Thirdly, the timing of growth spurts is analysed in light of windows of opportunity (Perez and Soete 1988) and strategic responses on behalf of leading companies (Mathews, 2005); and, not only companies, but potentially other actors of the innovation system, we may add. Ultimately, the study concludes by theorizing on the conditions of future leadership changes in the context of an increasingly globalized supply chain in the sector and dedicated efforts by the Chinese government to establish Comac as a major aircraft producer company.

3. A theoretical framework

3.1. On the catch-up of latecomers and the role of sectoral innovation systems

For a leadership change to occur, the forces that give advantage to latecomer entrants should exceed those that reinforce the leading positions of incumbents. There is ample supply of theories in support of both of these forces in the technological change literature. Incumbent firms, masters of the technology they had developed, have already established strong relationship with their customers, have access to technologies and can reap the advantages of economies of scale, market power, or reputational advantages (Hobday, 1995; Ferrier et al, 1999). Latecomers need to go through the costly and time-consuming process of accumulating technological capabilities, raising sufficient capital investments, and acquiring sufficient social and organizational capabilities to be able to challenge existing structures (Ames and Rosenberg, 1963; Abramovitz, 1986; Lall, 1992; Nelson and Pack, 1999). At the same time, late entrants are arguably in an easier position than the leaders for they can apply existing and proven technologies at much lower costs than those that paid the price of developed them, or can leapfrog certain technologies or stages. This has been widely discussed in the context of countries, industries and firms (Veblen, 1919; Gerschenkron, 1962; Kim, 1980; Tushman and Anderson, 1986; Hobday, 1995; Timmer, 2000; Lee and Lim, 2001). Studies have shown a rich set of evidence of successful catch-up[3] at firm and sectoral levels in a variety of industries, including automobiles, electronics or semiconductors (Kim 1980, 1997, 1998; Kim and Nelson 2000; Fagerberg 2000; Hobday 1995, 2003; Amsden

[3] In this study, catch up is defined as increasing market share in regional jet manufacturing. It should be noted that in the original context the term refers to per capita income convergence (c.f. Abramovitz 1986 or Szirmai 2005). As this almost always involves output growth acceleration due to the use of more advanced technologies (Fagerberg 1994), catch-up is often understood in a sectoral context either as a narrowing of the technological gap or as a convergence of market shares (i.e. Dalum et al 1999; Lee and Lim 2001).

1989, 2001; Mathews 2002; Westphal 2002; Lee and Tunzelman, 2005), or the central role played by manufacturing in the late industrialization of East Asia and Latin America (Fagerberg and Verspagen, 1999). A common feature in the experience of latecomers is that acceleration of growth was in most cases associated with a strategic and activist government policy (Amsden, 1989, 2001; Chang, 1993, 2003; Hobday 2003; Wade 1990; Cimoli et al, 2009).

Acknowledging the central importance of technological learning and innovation for sectoral catch-up, a growing body of literature focuses on how national and sectoral innovation systems (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Edquist, 1997; Malerba, 2002, 2004; Malerba and Nelson, 2012) influence innovation, competitiveness and industrial performance in latecomer economies (Lee and Lim, 2001; Mu and Lee, 2005; Malerba and Mani, 2009; Lee, Mani and Mu 2012). National and sectoral innovation systems framework have been found to be a particularly useful tool for analysing the growth (or lack of growth) of latecomer aerospace industries (Marques, 2004; Niosi and Zhegu, 2008; Marques and Oliveira, 2009; Mani, 2010; Vertesy, 2011).

A less often articulated, nevertheless crucial point to recognize when using the national and sectoral innovation systems perspective in the context of catch-up is that on the one hand, the functioning of the systems allow learning, absorptive, and innovative (in the context of the local as well as global markets) activities to succeed. On the other hand, innovation systems evolve as well, with their different components at different pace. Various studies have shown that there are discontinuities in the evolution of all the components of sectoral innovation systems. There are discontinuities and trajectory changes in technological development at the world frontier (Freeman and Perez 1988; Freeman and Soete 1997; Perez and Soete 1988), and punctuated equilibrium characterizes the long-run evolution of firms, organizations and industries (Abernathy and Utterback 1978; Romanelli and Tushman 1994; Tushman and Anderson 1986). Therefore, the co-evolution of technology, demand conditions, actors and the institutions regulating their network and interactions may well be marked by discontinuities and trajectory changes that can play a role in accelerating convergence or divergence of a given sector. At the industry level, the long-run evolution of latecomer aerospace industries was found to be interrupted from time to time as a result of declining competitiveness and macro-economic shocks, which in turn result in the reduction in innovative as well as industrial performance. While fundamental institutional changes can occur in optimal cases (i.e., in Brazil in the mid-1990s along the privatization of Embraer), otherwise the industry stagnates or declines (Vertesy and Szirmai 2010). Such changes may also be the results of strategic responses of firms to windows of opportunity, as proposed by Lee and Malerba (2013). Three types of windows of opportunity could be distinguished: the emergence of a new techno-economic paradigm that affects the knowledge-base of the system; changes in the business cycle or abrupt changes in demand; and new institutional environment or asymmetries created by governments. In what follows, we will investigate instances of leadership change in the regional jet manufacturing industry by examining various windows of opportunity and the responses given by firms or other key actors.

3.2. Preconditions for catch-up and leadership change

Consequently, a central question for this paper is to understand the preconditions for catch-up and leadership change in regional jet manufacturing. Apart from the emergence of windows of opportunity, we expect to find the accumulation of sufficient technological, organizational and investment capabilities, in order for key actors to be able to exploit the windows of opportunity. From a firms' perspective, a critical mass of experience and technological capabilities may be needed to have sufficient absorptive capacity to recognize the value of new information and make a strategic move (Cohen and Levinthal, 1990). The industry, a complex production and innovation system similarly needs threshold capabilities to undergo change. The readiness or flexibility of a given innovation and production system to react is crucial, but is not straight-forward, since aerospace products, including regional jets, are themselves complex and modular systems (Hobday et al, 2005; Dosi et al, 2003). This complexity is also reflected in the structure of the aircraft manufacturing industry, which, by the 1990s, transformed into a pyramid-like hierarchy, in which system assemblers are on top, followed by firms that develop and produce primary structures and systems in the second tier below, while component and subsystem producers supply them from lower tiers. Aerospace companies may have core competencies in multiple segments and tiers at the same time, i.e., system assemblers in one program and as co-developers and producers of components (risk-sharing partners) in another, which results in a complex set of collaborative and competitive interactions on various tiers. The landscape looked somewhat different in the 1980s, when regional jet producers still performed many activities in-house.[4] Nevertheless, the top of the pyramid is in the focus of this study, and consequently those preconditions of leadership

[4] Considering this change in industrial organization, one may call distinguish a "less mature" and "more mature" state of the industry, but this may be a bit of an exaggeration considering that the aircraft industry changed little inasmuch as the dominant design was crystallized soon after the onset of the jet age and the industry is characterized by incremental innovations (c.f. Frenken and Leydesdorff, 2000) – typical of what would be considered as maturity in the context of another sector.

change that concern such firms with core competencies in component or structure design and manufacturing, system assembly and marketing of aircraft.

Given the complexity of the industry and its costly products, the institutional environment in which it operates is similarly complex. The highly internationalized industry with producers and users located under very different political regimes is prone to be influenced in a very heterogeneous way in the course of its evolution. For instance, the competitiveness of a final product may not only be affected by changes the provision and cost of finance or skilled labour force in its home market, but also such changes taking place in the home market of its collaborating partners.[5] Political actors can significantly influence the competitiveness of a producer by providing export credits or demanding offset agreements in return for allowing market access. As a result, potential windows of opportunity may similarly involve multiple factors and affect different actors of the innovation system unequally. It remains a question to explore how the different actors contribute to creating the preconditions of catch-up and leadership change: whether they contribute to providing the necessary capabilities, facilitate the emergence of a window of opportunity or contribute to providing a strategic response.

3.3. What we know of latecomer aircraft manufacturers

Not only leadership change, but also sustained periods of accelerated growth and convergence are exceptional in the evolution of latecomer aircraft industries. Each case is special, but common patterns can be observed to synthesize some relevant conclusions from the growing literature on latecomers in aerospace.

First, the successful entry and catch-up of companies (often so-called 'national champions') depended on the provision of skilled personnel and technology from education and research institutes in their proximity and from more advanced countries, on access to finance and to international market in which the long-term, industry-friendly policies of their respective **governments played a crucial role** (Cassiolato et al, 2002; Marques 2004; Marques and Oliveira, 2009; Goldstein, 2002b; Vertesy and Szirmai, 2010; Maculan, 2013; Niosi 2013; Lukasiewicz, 1986; Niosi and Zhegu, 2005, 2010); India (Baskaran, 2001; Mani, 2010, 2013), South Korea (Texier, 2000). High capital and technology-intensity are the main barriers to entry to this industry that shows signs of maturity. Most of early leaders as well as

[5] Given the international character of the industry, drawing the boundary of an innovation system is rarely possible. For the sake of this analysis, when national-sectoral innovation systems are considered, the focus will be on the actors that are located in the country of the leading company.

latecomers benefited from the multi-purpose technology characteristic of aircraft and from research support and military procurement by governments.

However, companies failed in countries where governments excessively promoted a techno-nationalist and defence-oriented agenda without considerations of long-term competitiveness in the export market, and where an aerospace innovation system could not emerge (see the cases of Argentina or Indonesia (Hill and Pang, 1988; McKendrick, 1992; Eriksson, 2003; Hira and Oliveira 2007; Vertesy, 2011).

Second, ambitious but sound **company strategy** and an apt **management** were just as instrumental for success as a supportive government, as has been documented in the cases of both Bombardier and Embraer (Sarathy, 1985; Moxon, 1987; Ramamurti, 1987; Frischtak, 1992, 1994; Cassiolato et al, 2002; Goldstein, 2002a, 2002b; Goldstein and McGuire, 2004; Marques and Oliveira, 2009; Maculan, 2013; Zhegu, 2013), or the deficiencies noted in the case of the Indonesian IPTN (McKendrick, 1992).

Third, the **timing** of entry and of changes in strategy made a difference in two ways. On the one hand, the global structure of the industry has become more globally interconnected, and vertically integrated firms needed different resources and capabilities to be competitive in the 1970s and 80s than the ever more specialized ones in the 1990s and beyond. (See for instance, new entry of aerospace firms in Mexico (Martinez-Romero, 2013) or the maintenance sector in Singapore (Pang and Hill, 1992; Vertesy, 2013). On the other hand, windows of opportunity opened up only rarely. Techno-economic paradigm shift have been among the rarest causes of growth acceleration in latecomers, and most typically occurred at a smaller scale in certain modules or sub-tiers of the industry – such as avionics in the case of India, composite materials and other components in the case of Japan (Mowery and Rosenberg, 1985; Kimura, 2006, 2007; McGuire, 2007). Downturns in the business cycle, which regularly affect this industry so closely linked to GDP growth, has typically caused decline and crisis for manufacturers rather than accelerated growth. But downturns could also reinforce lower cost producers of more efficient aircraft, as in the case of Embraer of Brazil that managed to capitalize on demand for its cheaper aircraft.

4. An analysis of leadership dynamics in regional jet manufacturing

In this section we discuss how four companies, each of them a market leader in terms of aircraft deliveries for a number of years, responded to emerging windows of opportunity. First we look at British Aerospace and Fokker, two close competitors that have potentially faced similar windows of opportunity, because their growth periods both initiated in the 1980s.

Next we turn to the successful Canadian challenger, Bombardier, which dethroned the European companies. Finally, in the third case we look at Embraer, the only company from an emerging economy that succeeded in taking the leadership in regional jet manufacturing. In all cases we discuss the preconditions that ensured the success of challengers, the window of opportunities and the strategic response given by the new leader, and finally, investigate the reasons why the incumbent could not adjust or seize the same window of opportunity.

4.1. The emergence of the regional jet industry and the early innovators: British Aerospace and Fokker

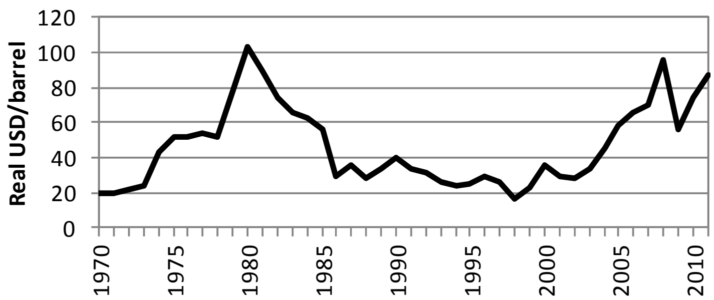
4.1.1. A window of opportunity for regional jets

A combination of factors resulted in a window of opportunity for the emergence and growth of the regional jet industry at the early 1980s. The rapidly increasing oil prices of the 1970s increased demand for fuel-efficient aircraft (See Figure 2). A new generation of turbofan (jet) engines with relatively higher bypass ratio became available on the market, significantly improving the competitiveness of jets also on shorter ranges where they could not compete economically with propeller planes earlier. Demand was further fuelled by the decrease in kerosene prices in the first half of the 1980s. Passengers, even if at some cost differences, showed preference for jets over propeller planes. The liberalization of US air transport market in 1978 increased the demand for efficient regional jets on shorter distances directly connecting regional airports by avoiding hubs, as well as connecting regional airports and congested hubs. More congested airports discouraged the operation of turboprop commuters that carried fewer passengers but took up the same or even more airspace as larger jets, given their slower speeds and that they were more prone to wake turbulence due to their lighter weight. Adding to these changing market conditions, regional jet makers could expect to exploit additional demand due to the need to replace aging turboprop aircraft.[6] In sum, probably none of these developments alone would have been sufficient to cause a radical change in the established airliner market, especially that they took place over a period of several years rather than at a single moment, but in conjunction (and in retrospect) they proved sufficient for the emergence of the regional jet market. These developments allowed airlines to select shorter range, smaller seating capacity jet aircraft out of strategic choice, rather than out of necessity due to technological constraints. Their success that allowed the

[6] See “100-seat jet market” *Flight International* 11 Feb 1989

emergence of the industry depended on country-specific preconditions and a set of strategic choices, which will be discussed subsequently.

Figure 2 Average annual crude oil prices in real terms, 1970-2011



Source: US Department of Transport

4.1.2. Preconditions for growth in the UK and the Netherlands

Industry actors had accumulated technological capabilities to produce commuter aircraft (both jets and turboprops) and military aircraft in both the United Kingdom and the Netherlands.[7] The predecessors and subsidiaries of British Aerospace and Fokker had a long, continuous history in aircraft manufacturing, a thorough knowledge of the market and specific demand of customers on the one hand, and had strong, established relationships with parts and component suppliers on the other hand. The aerospace innovation system was well rooted both in the UK and in the Netherlands (Cooke and Ehret, 2009, Broekel and Boschma, 2012), with world class universities dedicated to training skilled human resources and conducting research such as Queen Mary, University of London, Bristol, Cambridge, Surrey, Sheffield, or the Cranfield Institute of Technology or the Imperial College of London in the UK and the Delft University of Technology in the Netherlands, to highlight but a few. In 1980, the UK had the second largest aerospace industry in the Western world in terms of sales and employment (with sales at 10.6 billion US dollars; and 160 thousand employees) following the United States. The size of the Dutch aerospace industry was more modest, but still

[7] To highlight some of the most successful commercial aircraft programs in the UK following WWII, one could mention the 50-80 seater turboprop Vickers/BAC *Viscount* (444 built between 1948 and 1963), the first commercial jetliner de Havilland *Comet* (113 built over 1949-64), the de Havilland *Trident* medium-range jet (117 built over 1962-78), the Vickers/BAC *VC10* long-range jet (54 built over 1962-70) or the BAC/Aerospatiale *Concorde*, the world's first and only supersonic transport (of which 10 built in the UK over 1969-79) (for a more complete list, see "Post-war UK civil aircraft production" *Flight International*, 19 Dec 2006-1 Jan 2007). The Dutch commercial aircraft industry was virtually equal to the activities of Fokker, with its most successful own products, the F-27 *Friendship* (581 were built in the Netherlands over 1955-87) and the F-28 *Fellowship*, (241 built between 1967 and 1987).

substantial at the time, with over 20 thousand employees and a turnover exceeding 800 million US dollars.[8]

Both BAe and Fokker had designed and mass-produced jet aircraft in the upper range of what could be called regional jets (British Aircraft Corporation's BAC-111, and Fokker's F-28), and smaller, turboprop commuter planes (such as Hawker Siddeley's HS-748 or Fokker's F-27), even if the regional market was not yet as pronounced. Technological improvements in key sub-systems such as propulsion, lighter weight materials, avionics, that were mostly the outcome of the R&D efforts of producers in the larger segments, became available industry-wide. For instance, the *Tay* engine of Rolls Royce (Fokker's main engine producer partner) allowed significant efficiency increase and also noise reduction in comparison with the earlier *Spey* engine. Improvements in on-board electronics and the increased use of computers resulted in a reduction of cockpit workload and increase in operational efficiency and safety.

Strong linkages between industry leaders and policy actors on the one hand and a supportive industrial, trade and innovation policy on the other hand were crucial for creating the institutional conditions for growth. The UK government's legislations of 1977 and 1980 involving nationalization and later privatization (although keeping a 1 per cent golden share) of the major producers consolidated the industry and allowed the increase of efficiency. This allowed the sector to abandon, at least in the civilian market, loss-making, high-prestige enterprises such as the *Concorde* and focus on smaller scale but potentially self-sustaining projects. The importance of the favourable policy environment is clearly demonstrated in the case of Fokker. When the Dutch government agreed to bail out Fokker in 1987, the agreement by all stakeholders was that unless Fokker can self-sustain its activities, it cannot expect any similar direct public funding. In fact, the government, consequently, did not intervene to prevent the fall of Fokker a decade later. But these decisions also stand to testify that policy makers were influenced by market signals. In 1987, airlines (Swissair, USAir and KLM) and leasing companies (GPA and ILFC) strongly expressed their interest in seeing the launch of the new aircraft, while such explicit support was missing at the time of the next crisis.

[8] Sales are measured at 2005 prices; own calculations based on EUKLEMS and national statistical offices data.

4.1.3. Strategic choices of BAe and Fokker

Country-specific conditions alone would not be sufficient to explain the birth of the regional jet industry, strategic choices of companies have been equally crucial. The United States alone had the largest and most advanced aerospace industry, and US airlines showed a growing demand for jet commuters. The financial, technical and organizational capabilities were available for established American producers such as McDonnell Douglas (MDD) or Boeing, but these companies did not see the potential in the regional jet market, and perceived the larger size classes more lucrative. MDD, for instance, chose to make improvements to its successful DC-9 twinjet and position the new MD-80 family in the market above, rather than below a 100 seats. As a result, only European companies did not have to fear competition from leading American manufacturers and the 100-seat market became a niche.

The concept of the BAe-146 dates back to a 1973 Hawker Siddeley designed four-engine plane, which targeted the 100-seat jet market. That project was halted due to the 1973 oil crises and resulting global recession. Thus, as the window of opportunity was opening up towards the end of the decade, the newly created BAe (and Hawker Siddeley's successor) could re-launch the project as a clean-sheet design. BAe could make the most of collaborations both in-house (multiple BAe sites were located across the UK: Hatfield, Bristol, Manchester and Prestwick) and with external partners: control surfaces for wings and tail plane were designed and made by Saab-Scania of Sweden (the single risk-sharing partner in the project), wings were built (though not designed) by Avco Aerostructures of the US. Avco Lycoming provided the four engines, using a design that was already proven in the Boeing *Chinook* helicopters. BAe financed most of the development from own funds (to the amount of 350 million GBP). The design utilized the family concept in order to cut costs for producers and for users by increased commonalities in the three versions of the 146 (-100, -200 and -300) that differed only in size.

Unlike BAe, Fokker strategically decided against a clean-sheet design, but to modernize and re-engine its F-28 *Fellowship* twin-engine aircraft of the 1960s into a larger, 100-seat jet, the F-100. The company did not have too many options, as its very successful smaller turboprop commuter plane, the F-27 *Friendship* was also nearing the end of its production cycle. In response to market demand, Fokker had to finance the modernization and upgrade of both, rather different models. These parallel developments, which were eventually more significant upgrades of the two models, resulted in delays, cost increase and a near-bankruptcy, which is why only in 1988 did Fokker manage to deliver its first F-100 jet. The company initially planned to introduce a family of aircraft about the same time, with a 130-

seat version at the larger end and a 70-seater shortened version on the lower end. However, it only had the capacity to realize this latter, the F-70.

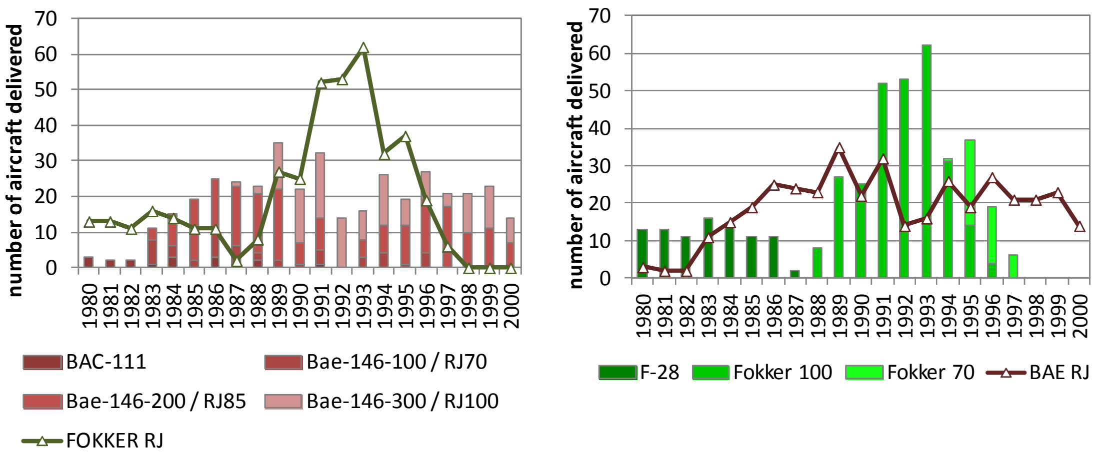
Fokker, in order to overcome the limitations in its financing and production capacity, entered into partnership agreements with Shorts of Northern Ireland to produce wings, with Dowty to produce landing gears. It also contracted the US based Grumman to build nacelles and the thrust-reversers. Moreover, Fokker's room for strategic manoeuvring was constantly limited by its size and liquidity position, and the history of the F-100 and F-70 were marked by a number of crises. In 1987, towards the end of the development phase, it faced severe cash-flow problems which resulted in the government bail-out – mentioned earlier. The higher-than-expected costs of development of two projects in parallel outweighed other problems such as shortage of engineers or higher sales prices due to low value of the US dollar. Five years later, in 1992, Fokker was once again facing challenges amidst the global recession. Despite implementing cost-cutting measures, its profitability was low and its long-term survival as a stand-alone developer was at risk at a time of global aerospace mergers and shakeout. With an aim to maintain its systems leadership position, Fokker agreed to be taken over by the German DASA, which offered only a temporary solution to its financial problems (Heerkens and Ulijn, 2000). Yet it was also the same time when Fokker managed to significantly economize its operations and achieve its highest delivery rates (Figure 3).

The main sources of market leadership were the competitive technical properties of the aircraft offered by the two companies. For the BAe-146 family, its uniqueness included the passenger comfort it offered (BAe opted for a "wide narrow-body" fuselage, where the costs in increased drag were offset by greater comfort offered by the 11ft-plus cabin width, the size of previous-generation long-haul jets such as the B-707), its noise certification and the versatility of operations. The BAe-146 was designed to be able to fly steep approaches (i.e. London City airport), operate on short runways (owing to the four-engine design), to fly many short legs without refuelling. A derivative was also sold on the cargo market as the "Quiet Trader" aircraft.

In the case of the F-100, Fokker responded to airlines' demand for cost-efficiency by offering relatively low structure-weight per seat as a result of using composite materials (for the flaps, rudder, elevator, engine, nacelles, floor panels, cabin interior and wing and tail fillets) and by guaranteeing the longest structural life cycle of parts. In addition, the F-100s were equipped with the reliable, efficient and quiet twin jet engines recently introduced by Rolls Royce. All this contributed to relatively lower operation costs per passenger.

It is interesting to note that the two products and companies competed neck and neck over the 1980s and 1990s and had many similarities, including the fact that half of the value of both was produced in the UK and both had the same list prices[9]. Both BAe and Fokker recognized that the regional jet market required products with cost-efficient performance and companies with sufficiently large production capacities. It was their misfortune that when a new window of opportunity opened in the middle of the production cycle, two latecomer companies could reap the moment and take efficiency and competitiveness one step further.

Figure 3 Number and types of regional jets delivered by British Aerospace (BAe, left) and Fokker (right) in contrast (1990-2000)



Source: www.airlinerlist.com (retrieved: June 2012)

5. Bombardier gaining leadership in the 50-seat regional jet market segment (1990s)

5.1. Preconditions for growth

It was no surprise that the company that took the leadership position was based in Canada, due to a number of reasons. Considering the sectoral innovation system in aerospace, Canada had accumulated a very strong knowledge base over the preceding half a century. Aerospace firms have been among the largest R&D spenders of the country and showed a revealed comparative advantage for decades. The National Research Council (NRC) was a key source of fundamental research for the industry since the 1950s, supporting the development of gas

[9] Obtaining actual sales data is difficult; according to one source, in 1989, both were offered for 21.5 million US dollars ("100-seat jet market" *Flight International* 11 Feb 1989), however, the actual sales prices could substantially differ.

turbines and offering wind tunnel tests (Niosi, 2000).[10] The Montreal and Toronto clusters gave home to a set of companies with a long history of competitive aircraft, parts and components (including engines) development and manufacturing (including Bombardier, Bell Textron, Pratt & Whitney, or Honeywell, to name but a few), which gave home to advanced research as well, thanks to access to skilled human scientists and engineers from excellent advanced university education programmes in the relevant fields (Niosi and Zhegu, 2005). The Canadian aerospace industry has very strong ties with the US industry. Canadian firms have access to US government contracts since 1959 and maintain intensive technology- and market-oriented global collaborations (Anderson, 1995, Niosi and Zhegu, 2010). With an aim to facilitate initial sales, the government also provided support to Canadian exporters through repayable loans from the Export Development Corporation. In sum, the institutional setting in the industry and innovation system offered a favourable climate in Canada.

In addition, significant advances have been made in information and communication technologies (ICT) which on the one hand offered significant cost-saving for producers in managing design and production activities. Bombardier, in particular, has gained experience in these manufacturing activities in other transportation equipment sectors. On the other hand, ICT offered efficiency gains for users of aircraft; airlines became increasingly able to fine-tune their services and offered capacities to point-to-point travel demand.

5.2. The windows of opportunity

The windows of opportunity that turned out to be instrumental for Bombardier's leadership opened up in different forms and at different times. First of all, "technological windows" offered the potential to make ever smaller regional jets economically viable as the newest generation of engines brought further efficiency improvements. In comparison with the 3:1 bypass ratio of the Rolls Royce *Tay* engine selected by Fokker for the F-100, General Electric's CF-34 engine family introduced in the mid-1980s offered over 5:1 bypass ratio and greater thrust-to-weight ratio (Table 1). In addition, the diffusion of information and communication technologies offered efficiency gains in running complex organizations such as a large company with production and development units in different locations.

Second, the "demand window" for aircraft in the regional class of up to 100 seats remained open throughout the 1980s, which spurred the development of new aircraft. As demand for BAe and Fokker jets for the 100-seat segment of the market was increasing,

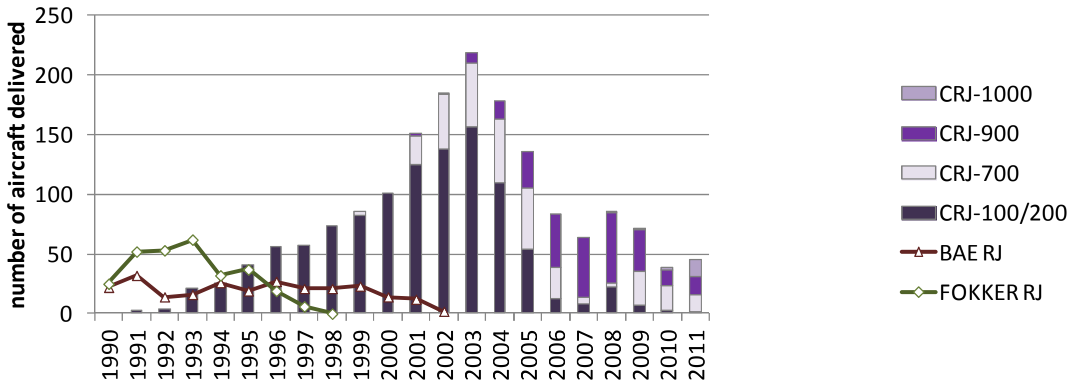
[10] Niosi (2000) notes that the National Aeronautics Establishment of the NRC, created in 1958, operated the only wind tunnel of Canada and supported the design of all aircraft and engine models for over a decade, i.e. the De Havilland wing designs.

airlines as well as aircraft makers began seriously to consider the idea of introducing jets in a market segment served until that point by smaller, propeller planes only. Many of the characteristics of a window of opportunity for this 50-seat segment were similar to what a decade ago ushered in the regional jet era. The established hub and spoke system in the United States meant that a previously unseen number of communities were now connected to major hubs, served by smaller commuter propellers. Hubs were in competition, and regional jet service allowed increasing their reach and thus their market share. The thriving commuter market, however, caused congestion at hubs and a longer travel time in comparison with point-to-point travel. Introducing jets on the feeder routes and for new city-pairs could boost efficiency. And given the opportunity to choose, passengers perceived jet aircraft to be safer, more modern and more comfortable than turboprops. In Western Europe, a new stage of economic integration also boosted demand for air travel for relatively shorter distances.

Those companies that recognized and responded to these windows of opportunity by initiating the development of new aircraft in the late 1980s were “rewarded” with additional windows of opportunity that coincided with the stage when new 50-seater regional jet projects reached serial production in the 1990s. This time it was the combination of “demand windows” and a “regulatory window”. Following the Gulf War, oil prices were low and in constant decline (Figure 2), allowing airlines to cater consumer demand for the comfort of jets. Air transport around the world was expanding and regional jets could offer more frequent feeder connections. In Europe, the market was opening towards the former Eastern Bloc. In parallel, the introduction of “scope clauses” in the US turned out to be a crucial regulatory window. Scope clauses were meant to defend the higher wages of larger legacy airlines’ pilots against the lower wages paid by regional airlines, which were established or subcontracted to fly feeder and commuter routes and gained significant market share in domestic air transport. In order to keep a cap on the upward extension of relatively cheaper commuter services, pilot unions and airlines settled with the agreement that subcontractors cannot fly aircraft larger than 50 seats. Scope clauses had a major impact on the regional aircraft industry as they effectively excluded existing regional jets with 70-seats from a large part of the regional market. These regulations also gave an advantage to jets rather than modernized turboprops in the 50-seat market, as airlines (given the lower fuel price) could offer more frequent, more comfortable connections with jets.

There were additional factors that fuelled demand for smaller regional jets in the 1990s. Apart from passenger preference for convenience offered by jets (further boosted by high-profile turboprop commuter crashes), the relatively low and declining fuel prices confirmed company strategies that betted against turboprops and introduced smaller sized regional jets. Although these years were turbulent times for the aviation industry, demand in many lower volume markets were expanding, including the opening up of the former Eastern Bloc in Europe, allowing airlines to adjust schedules building on regional jets.

Figure 4 Number and types of regional jets delivered by Bombardier in contrast with BAe and Fokker



Source: www.airlinerlist.com (retrieved: Jun 2012); Bombardier Annual Reports

5.3. Strategic response

Bombardier was one of the many aircraft makers that recognized the need to respond to the windows of opportunity that emerged for the 50-seat segment in the late 1980s. The expectations about the economic viability of 50-seat jets for routes below 500 nautical miles divided manufacturers, and many of them betted on turboprop aircraft. In fact, most of the European producers with a stake in the commuter market calculated with a typical 200 nautical mile trip length on 50-seat routes. Jets hardly offer a 15 minute block time advantage on such routes, while their fuel costs are nearly double. The cost to develop a new regional jet was calculated to be about a billion US dollars, costs that appeared unlikely to be recovered through product sales.[11] Both incumbents on the 100-seater regional jet market, British Aerospace and Fokker, had their own smaller turboprops with a seating capacity of around 30 to 60 to offer for the 50 seat market. In the case of Fokker, it was the F-27 derivative F-50, in the case of BAe, the Jetstream 41 and the ATP.[12] They knew well the tight competition these aircraft were facing, as the French-Italian ATR-42 was already launched in 1984, and Saab, which saw rising demand for its 34-seat SF-340 (jointly built with Fairchild) started to develop a bigger and faster model, the 50-58-seater Saab 2000 in 1988. Fokker, from its part,

[11] "The case for the turboprops" *Flight International* 4 Mar 1989

[12] Their first flights of the Fokker F-50 took place in 1985 and serial production started in 1987; in the case of the BAe ATP both events occurred a year later. The BAe Jetstream 41, a stretched version of the 1980s model first flew in 1991 and was serially produced the following year.

had already drawn its conclusions from the failure to sell its VFW-614 44-seat jet in the 1970s.[13] At the same time, the company did not have the capital to start a new project with its huge investments already made in the two parallel aircraft development programmes. Once the F-100 was launched, Fokker did plan to respond to demand in the below-100-seat market with a shortened version, the F-70. This derivative of a plane optimized for a larger market at an earlier time, however, turned out not to be competitive among the smaller-sized jets.

In retrospect, the fact that the incumbent firms failed to respond to the emerging market niche with a radically different design (out of choice or out of necessity) very much follows the typical case of an "incumbent trap". In the standard model of incumbent failure, described by Hill and Rothaermel (2003), incumbents have an incentive to pursue incremental, rather than radical innovation – in this case, it is the introduction of a shortened or stretched version of an existing model, given their sunk costs in the development. They are embedded in established industry networks where co-production arrangements are built around the existing technology. They lacked investment capacity but were not ready to circumvent this limitation by establishing new joint ventures, in which way they were unable to embrace the newest technology. However, at that point, during the late 1980s and even the early 1990s, it would have been too early to talk about failure in the case of the incumbents, as the 100-seat market was experiencing rather strong demand. The arguments against a 50-seat regional jet were valid; such a project involved a high element of risk and a gamble on low oil prices, so it is hard to challenge the logic of BAe's and Fokker's response.

Interestingly, the British company Short Brothers (or Shorts) also considered launching a 48-seater regional jet known as the FJX, a radically new design in comparison to its older, angular turboprop models. However, the FJX never progressed beyond the concept phase, as Bombardier, recognizing a potential competitor, acquired the company in 1989. The only successful contender in the 50-seat regional jet market, apart from Bombardier, was Embraer. The Brazilian state owned enterprise decided on a major upgrade of its rather successful 30-seat turboprop commuter into a regional jet. Design work, launched in 1989, was severely delayed by financial problems and the difficulty to find appropriate partners. Only once Embraer was privatized did the 50-seat EMB-145 perform its maiden flight, four years later than the leader, Bombardier's CRJ. The remainder of this section will discuss the success of Bombardier, while Embraer will be in the focus of the following one.

[13] This unique design of a small jet with its engines on over-wing pylons offered relatively poor performance due to its wide fuselage (increased drag) and weaker engines. Technology was evidently not sufficiently advanced for an efficient and reliable regional jet at the time of increasing fuel prices and the project was cancelled in 1977.

Bombardier's strategy to take advantage of the windows of opportunity rested on three elements. First, the accumulation of technology through acquisition: Bombardier, the transport equipment manufacturer (producer of snow mobiles, locomotives and light rail transit) gained strong development and manufacturing capabilities by acquiring troubled companies with advanced products, including business jet maker Canadair from the Canadian government in 1986, the historical British component supplier (and potential competitor) Short Brothers in 1989, the business jet producer Learjet in 1990 and turboprop commuter plane maker de Havilland in 1992. This established Bombardier as a company offering a diversified range of related products, including business jets, commuter aircraft, and components. With the financial consolidation of the indebted companies and the introduction of a new management system, it could simultaneously launch the Learjet and Global Express business jets, the closely related Canadair CRJ regional jet, and the Dash 8-400 turboprop, all addressing the regional jet and commuter market niche and the executive market. By standing on many pillars, Bombardier could draw upon both the Canadian and US aerospace innovation system. The main reason Bombardier could launch the 50-seat regional jet at a competitive price was its choice to rely as much as possible on an available design, Canadair's *Challenger* business jet. Stretching the fuselage and its wings, adding additional exits and making smaller modifications to subsystems in order to prepare the aircraft for regular regional airline service, it was estimated that Bombardier kept development costs at about a third the costs of a clean-sheet design. Bombardier financed the development costs from the conglomerate's own funds as well as from repayable loans received from the Canadian federal and the Quebec provincial governments.[14] It also speeded up development time: design phase began end of 1987, the first CRJ flew early 1991, and by late 1992 Lufthansa CityLine, the launch customer received its first aircraft. By 1993, it secured 30 firm orders from two regional carriers of Delta Air Lines, Comair and SkyWest and soon Bombardier found itself in the need to increase production capacity to be able to respond to demand by North American and European airlines. The demand for the 50-seat jet segment was boosted by the "second set" of windows of opportunity outlined in the previous section (lower fuel prices, application of scope clauses and overall efficiency gains), as well as highly publicized commuter turboprop crashes in the US in 1994 and 1995 (ATR-72 and a BAe Jetstream). By 1996, when Embraer followed Bombardier with the first delivery of its 50-seat ERJ-145 jet, the competitive landscape had changed significantly. Regional jet deliveries have overtaken turboprops in the 50-seat market (Figure 5), and European producers of

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[14] Of the 275 million CAD project costs, 78 million was government financed, according to "Routes to Success" *Flight International* 30 October - 5 November, 1991

regional jets were on the losing end of the strong price war. The overall costs of European aircraft were significantly higher due to the relatively weak US dollar and less efficient production; the smallest models (the newly launched Fokker F-70 and the BAe RJ70) were too large for the scope clause limitations of the US market. As the end of the decade saw a growing interest in scaling up aircraft size, Bombardier once again capitalized on the relatively lower development costs of launching a 70-seat stretched derivative of the CRJ200, the CRJ700, and on its increased product portfolio.

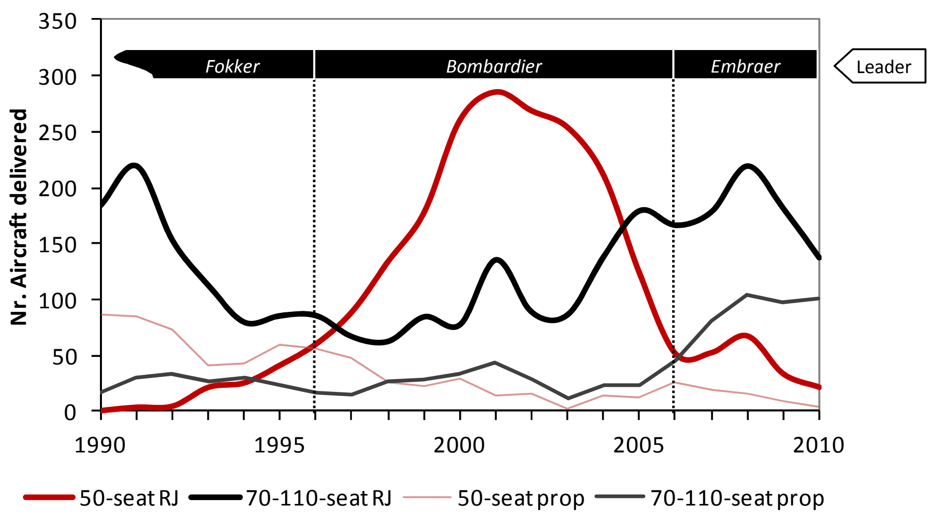
By focusing on its core competence, which was joint product development with risk sharing partners, system assembly and marketing, and strongly pushing for offering a whole range of related products (CRJ family from 50-100 seats), Bombardier gained significant costs advantage. The company realized significant efficiency improvements by introducing "the Bombardier Manufacturing System". This offered cost, time and space optimization with the computerization of workflow and logistics, the use of just-in-time logistics and reliability testing on the production line rather than on the flight line, with closer interaction between departments, and the simplification of manufacturing tasks. Bombardier also strategically chose its risk-sharing partners in a way to keep their number limited but have available capacity for delivering to large-scale orders, which became a crucial factor, one that contributed to the decline of Fokker.[15] A good indicator the success of Bombardier's strategy is the fact that it produced more regional jets in a year than any of its competitors had before and kept the global market leadership for almost a decade following 1996 (Figure 4).

Bombardier became the leader in regional jets by essentially creating the 50 seat market, rather than attacking the incumbents in their own size class. It is interesting to note that apart from Embraer, incumbent companies did not follow suite when they saw the windfall in this lower segment. European companies that argued against the small regional jets in the late 1980s were now in a difficult position due to industry-wide developments in the 1990s. The declining military spending after the end of the Cold War, the global recession and the poor performance of airlines resulted in lack of capital and major structural change in the industry and a long wave of mergers and acquisitions, and strong price competitions for new aircraft (USITC 1998). Furthermore, as Embraer gained a strong stand in the segment, it became clear that there was hardly more room for new players. The window of opportunity offered by the cheap oil price did not last long: the 50-seat regional jet became less and less

[15] An interesting element of the competition between Fokker and Bombardier is that Shorts, the company acquired by Bombardier, was a component supplier of Fokker. Bombardier could thus learn from the negotiations with Fokker, already before introducing the Canadair regional jets, how crucial capacity was for competitiveness.

economical to operate in the post-9/11 era. The period 2001-2006 saw a decline in this segment as steep as growth was in the previous decade (Figure 5). Yet both Bombardier and, with a few years' delay, Embraer built a thousand of their 50-seat jet each, which marks an exceptional achievement in the aircraft industry. Bombardier owed its leadership in the 1990s to being a first mover and a fast mover, able to seize the windows of opportunity and launch a new model and produce in large quantities in relatively shorter time than the competitors. However, in light of the changing demand patterns, it turned out to be slower to respond than Embraer.

Figure 5 Size and type competition in the regional market



Source: Own calculations. *Note:* 'RJ' stands for Regional Jets, 'prop' stands for turboprop aircraft. Data covers all ATR, Boeing/MDD, Bombardier, British Aerospace, Embraer, Fokker and Saab models in the 50 (40-60) and 70-110 seat category.

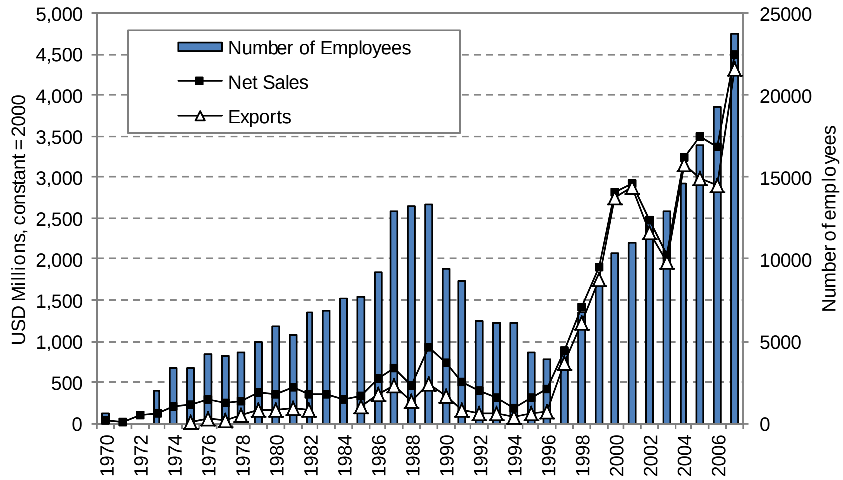
6. Embraer gaining leadership in the 70-120 seat regional jet market segment (2005 –)

6.1. Preconditions for growth

Despite being located in a developing country, Embraer showed, in many ways, similarities to the other three companies that became leaders of regional jet production. Most importantly, by the time it started producing regional jets, it already had strong experience in the design, assembly and marketing of propeller-driven, but pressurized regional-scale commercial aircraft, and in producing jet aircraft for military use. These included the 30-seater, 550 nautical mile range EMB-120 *Brasilia* introduced in 1983 and the AMX joint fighter project of the late 1980s.

Brazil looks back to a long history in small aircraft production and aeronautical research. After mass production of sport planes and military trainers under license ended after the Second World War, the government agreed to finance aeronautical research and training in order to maintain and further enhance existing knowledge and skills. In the 1950s and 60s, ITA, the institute for training aeronautical engineers and the technological research organization CTA became the backbone of the emerging Brazilian aerospace innovation system (Vertesy, 2011). It was a research team at the CTA that designed a 20-seat turboprop, the *Bandeirante*, which appeared strong enough to fill a market niche in the US commuter market. Serial production and marketing of the aircraft required a new company, which was established as a state-owned enterprise in 1969. This facilitated public finance, access to military procurement and tax credits, however, Embraer has cultivated elements of an entrepreneurial culture throughout its history. This combination was crucial to overcome the technological and market barriers faced by a newcomer from an emerging economy. The linkages with the Brazilian Air Force and the government were strategically used to finance development (CTA remained very closely linked to Embraer), access technology and protect the nascent market (strategically select partners while exclude competition from others) and facilitate export market access (use diplomacy to speed up certification of new models), but the initiatives were supplied by the company leaders (Ramamurti, 1987; Silva, 2002). All this allowed the accumulation of capabilities to use and modify technologies developed elsewhere and used in products that Embraer, by far the leading company of the sector in Brazil, successfully developed for niche markets, much of it for export (Figure 6). Embraer’s 20- and 30-seater aircraft offered competitive response to growing demand in the commuter market in the US; 500 *Bandeirantes* and over 350 *Brasilias* were built. However, the state-owned model that worked for the emergence of Embraer as a global player from the 1970s until the late 1980s became a burden after a political and financial crisis hit Brazil, and a fundamental reorganization of the technological learning, innovation and productive activities in the aircraft industry became necessary for survival in the new competitive landscape (Frischtak, 1992, 1994; Cassiolato et al, 2002; Marques, 2004).

Figure 6 Growth, decline and growth of Embraer (Sales, exports and employment levels, 1970-2007)



Sources: Embraer Annual Reports, Frischtak 1992, Ramamurti 1987, Cassiolato *et al.* 2002

As a turboprop regional aircraft manufacturer, Embraer was well aware of the windows of opportunity for small regional jets opening up in the late 1980s. After market studies, it officially launched the 50-seat EMB-145 regional jet project in 1989. Embraer could not directly benefit from the favourable global market conditions during the early 1990s in the same way as Bombardier, because of the rigidity in the institutional arrangements of the industry and innovation system in Brazil. Development of the EMB-145 stalled and the Brazilian financial and economic crisis, in combination with the difficulty to find risk sharing partners resulted in the near bankruptcy of Embraer and a need to downsize operations. The privatization of Embraer[16] in 1994 brought a major management overhaul for the company and a fundamental institutional change in the Brazilian aircraft innovation system (see Vertesy and Szirmai 2010). Decision making became more efficient in the new private structure, and the company could reposition its core competence in co-design, system integration, sales and after-sales support, similar to Bombardier. To mitigate the limited availability of funding in Brazil, Embraer chose to co-developed (and co-produced) with risk sharing partners located around the world. The use of advanced information and communication technologies allowed virtual collaboration, the weaker domestic supply chain did not prevent Embraer from offering highly competitive products as it could rely on the same component and subsystems suppliers as all the major aircraft makers. By the year 2000, the delivery rates of the ERJ-135/145 family (highly similar models covering the 35-50 seat segment) exceeded Bombardier's CRJ200. Brazil's supportive industrial and export policy

[16] Buyers included Brazilian and US-based non-aerospace sector investors, while the government retained a golden share in Embraer.

was also crucial to facilitate exports, as the sales of Embraer was also primarily global in scope. A one billion dollar credit line from the Brazilian Development Bank BNDES in 1997, and the PROEX export financing scheme (offering interest rate equalization for buyers, subsequently challenged by Canada in a WTO trade dispute) show that even after privatization, Embraer received significant government support.

6.2. The windows of opportunity

The demand window that heralded yet another leadership change opened as fuel prices began to increase once again after the turn of the millennium (Figure 2) to the point of raising doubts about the viability of existing regional jets in the 50 seat range. This change shifted demand for larger regional jets that offer lower fuel consumption per passenger, or for turboprops with lower operating costs in the smaller, 40-70 seat range. The competition between airlines intensified with the diffusion of low-cost carriers along the traditional network and regional carriers, making airlines ever more sensitive to cost and efficiency. The regulatory cap also followed the economic realities and existing scope clauses were re-negotiated and relaxed from 50 to 70 seats, and beyond. Forecasts of the major aircraft producers became rather optimistic about the prospects of the 100-seat segment (foreseeing over 2,000 new aircraft up to 2020), driven partly by income and population growth in emerging markets and by the need to replace aging narrow-bodies of the 1960s and 70s (such as the B-727 and DC-9s) in America and Europe. This replacement process was further accelerated on the one hand by the higher operating costs of older models, and by states imposing stricter noise regulations, which effectively banned old aircraft from operating in Western airspace.[17] In addition, more and more airlines recognized the potential of reducing aircraft size to 100 from the typical 150-180 seat range to allow greater frequency and increasingly direct services, and also connect new city pair connections (USITC, 1998).

Technological windows of opportunity for the regional jet industry were probably less important for this period. Nevertheless, results of incremental improvements in jet engines, in avionics, in the diffusion of composite materials were becoming available industry-wide, at specialized second- and third-tier suppliers, altogether increasing efficiency. In parallel, technological improvements in the aviation infrastructure (in air navigation services, air traffic management) resulted in greater capacity to handle the growing air traffic and allow more economical operations.

[17] As an alternative, some operators found noise reduction kits, or “hush kits”, to be temporary solution, while others pushed aircraft manufacturers to re-engine existing aircraft.

Larger, 100-seat regional jets that were developed in response to the windows shown above were further benefitting from another window of opportunity. The volatility of the markets (i.e. the 9/11 shock hitting the airline industry and the financial crisis starting in 2008) turned out beneficial for 70-120 seat regional jets, and many operators of larger civil aircraft in the 150-plus seat range shifted to smaller size. These airlines found the lower cost of a regional jet more appealing than a B-737 or an A-320 at a time when liquidity mattered. Network carriers in particular appreciated their flexibility, offering greater frequency at times of boom and a way to defend market presence and network spread when travel demand dropped. Just as a relatively long period of low fuel prices and the strict scope clauses offered an opportunity for the 50-seat regional jet to become the leading product in the 1990s, so did increasing fuel prices, market volatility and the relaxation of scope clauses turn the 70-120-seat regional jets into the leading product of the first decade of the 2000s (Table 1).

6.3. Strategic response

As the windows of opportunity for the 70-120 seat jet market opened in the late 1990s, the region jet industry was poised to become more crowded than ever before. Many interpreted the 1997 bankruptcy of Fokker as an opportunity to enter and deliver on the unfulfilled orders, rather than as a warning sign for how cost-efficiency affects competitiveness. The largest "air shows" around the world echoed announcements of new regional jet development programmes, by incumbents European and American incumbents as well as Asian newcomers. Three types of strategic responses emerged: re-engine existing models, resize existing models, or develop a new design.

British Aerospace, the real incumbent, had already re-engined and modernized the BAe-146 family in 1993 which it marketed as the Avro RJs. However, both the high production and operating costs of the Avro RJs (owing to the four-engine design) put pressure on the company to make further improvements, either with yet another change of engines, or with a clean sheet design. BAe Systems (the company formed with the merger of BAe and Marconi Electronic Systems in 1999) eventually made the less ambitious choice to re-engine existing designs, but made it too late, and was forced to exit the industry in 2002.

Boeing and Airbus, the two giants that remained standing after the shakeouts of the large civil aircraft industry in the 1990s, had their strength in making aircraft with 150-seats or more. In light of the windows of opportunity they recognized the potential to save development, marketing and operational costs by extending their families downward to a 100 seats. Although never fully committing themselves to enter the excessive competition of the regional jet market, they both tried different ways not to be caught empty-handed. With its 1997 merger with McDonnell Douglas, Boeing "inherited" the 117-seat MD-95, the latest descendant of the DC-9 family, which it marketed as the Boeing 717. Despite the mediocre sales performance, Boeing continued to offer the product until 2006, after it proved to be outcompeted by Embraer and Bombardier. Boeing also marketed the 737-600, at the time the smallest member of its most successful 737 family, for the upper end of the regional jet market. Similarly, Airbus offered the A-318, the smallest member of the A-320 family for the same segment. However, neither of these derivative aircraft proved successful, as the original models were optimized for the 150-180-seat market, and the advantages offered to network carriers with fleets including larger models of the family could not offset their higher costs in comparison with regional jets. Airbus also made a cautious attempt to co-develop and produce even smaller-sized aircraft, the AE31x in collaboration with Alenia, AVIC of China and Singapore Technologies Aerospace. The program never took off due to insufficient capabilities and concerns about technology transfer to China.

In contrast to Boeing's and Airbus' attempt to target the 70-120-seat market segment by resizing larger models, Bombardier's targeted it from below, followed a proven strategy of relying on existing designs. Just as the CRJ200 was a stretched version of the Challenger business jet, the CRJ700, the -900 and the -1000 were stretched and re-engined versions of the CRJ200. However, the limit of stretching the original design was a hundred seats, and Bombardier was hesitant to make the move to higher seat ranges by introducing radical design changes. In 2000, it shelved the billion-dollar "BRJ-X" project that foresaw a radically new design for a family of aircraft with 85-115 seats in favour of the 90-seat extension of the CRJ family offered by the -900, with development costs being an order of magnitude lower. Beside the costs, Bombardier was unwilling to challenge the lower end of the large civil aircraft market segment. Only after Embraer introduced its new E-Jet series did Bombardier decided to revisit the idea. The development of the new 100-150-seat C-Series regional jet was delayed by lack of orders, only to be officially launched in 2008, with a first flight in 2013.

Four other companies chose the strategy to go for a new design. Two of them, AVIC of China and IPTN (later DSTP) of Indonesia, lacked the necessary preconditions to develop a competitive regional jet for the global market; AVIC's ARJ-21 successfully took off but are still today awaiting certification by FAA, DSTP's 2130 jet never even took off (Vertesy, 2011). Fairchild Dornier has already proven their design capabilities with the 328Jet, the jet version of its 32-seat aircraft when it made an attempt to enter the 70-110 seat regional jet segment with the 728/928 family. The company, in the midst of mergers and acquisitions and with its costly production, proved unable to respond swiftly to the windows of opportunity. It introduced the smaller 328Jet at a time when the market was already shifting to larger sized regional jets, and this commercial failure also brought down the 727/928 family in 2002. The only successful innovator with a new product design specifically targeted for the 70-110 seat range turned out to be Embraer, which successfully reaped the advantages of its new niche.

Embraer recognized the value of entering the 70-120-seat market early on, while it was still at the height of production of the ERJ-135/145 family. Based on feedback from existing and potential customers, the core of its new strategy was to optimize a regional jet family for the 70-110-seat market.[18] It was a direct response to the price competition pushed by the spread of low-cost carriers, the need to right-size offered seating capacity to demand, and to the relaxation of scope clauses. The company could build on its 30-year experience in producing for the global commuter market, as well as on the experience from the risk sharing partnerships already established during the mid-1990s. In a stronger position after the success with the ERJ-135/145 family, Embraer further streamlined for cost optimization with the introduction of the larger E-Jet family (ERJ-170/175/190/195) during the early 2000s. Embraer took a 45 per cent stake in the project, while the rest were taken by the 16 partners were chosen in a competitive selection process.[19] Interactions between the partners were facilitated by relying entirely on digital design and data sharing and utilization of a Virtual Reality Center. These changes not only raised the level of technological precision, but also significantly reduced development time and costs. In addition, even if the E-jets are clean-sheet designs, beyond the within-family commonalities, they share some degree of commonalities with its predecessor, a further source of cost saving.

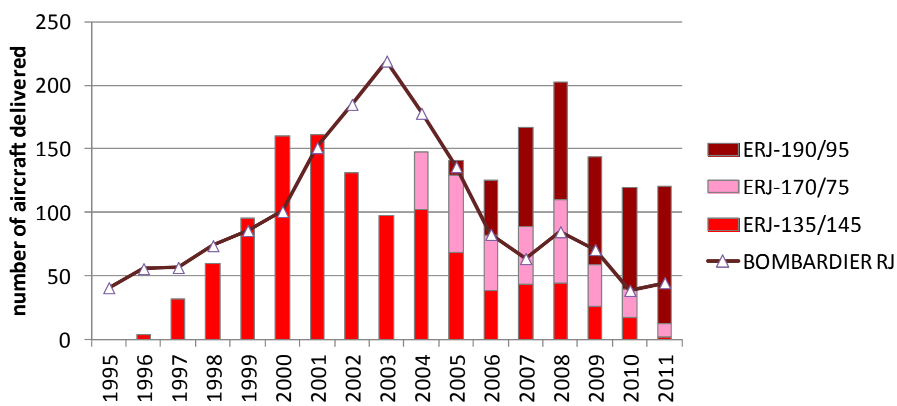
The 80-seater ERJ-170 first flew in February 2002 and was already certified two years later and delivered to the launch customer. A slightly stretched version with 88 seats, the ERJ-175 was introduced a year later. The first 110-seater ERJ-190 flew in 2004, followed by the 122-seater ERJ-195 a few months later. The American low-cost carrier JetBlue became the launch customer with an order of 100 and option for another 100 planes. The 190/195 planes have a longer redesigned wing and greater engine thrust. With these planes Embraer has directly become a competitor of not only the largest members of the BAe-146-300 or Avro

[18] It publicized the strategy as the “70/110 rule”.

[19] Some of the main partners were GE, the single producer of engines (a package worth around 20 per cent of the plane price), Honeywell (a GE subsidiary by now) responsible for avionics, Gamesa of Spain responsible for the tail section and rear fuselage. Liebherr supplied the landing gear and Kawasaki Heavy Industries of Japan was in charge of parts of the wing control surfaces made using composite materials and pylons, although this last collaboration did not go smoothly and was changed for “younger member” products of the family.

RJ100, but also the larger plane makers Airbus and Boeing, challenging their smallest models (the A318 and the B717 and 737-600s respectively). The source of competitiveness for Embraer's products is its price and operating costs. The location in Brazil and the lower labour costs has only a limited effect on the prices, given the fact that Embraer aircraft are overwhelmingly (90 per cent) produced outside Brazil (despite efforts to increase the local manufacturing share). Export credits funded by the government play an important role (although they less favourable for airlines than they were in the 1990s, when below-market rates triggered a WTO dispute with Canada). In sum, the efficiency gains and the highly competitive prices allowed Embraer to significantly expand the production cycles which allowed it not only to catch up with Bombardier, but also to overtake it by 2006.

Figure 7 Number and types of annual regional jet deliveries by Embraer in contrast with Bombardier



Source: Embraer and Bombardier Annual Reports.

Embraer has also been expanding its capacity; apart from the original plant ('Faria Lima') at the airport of Sao José dos Campos (near CTA/ITA), Embraer opened another site in Eugenio de Melo in 2001, specializing in the development and manufacture of tools and tubing, welded and forged parts, as well as large cabling projects. This site also hosts a school for the Engineer Specialization Program, a postgraduate, in-house interdisciplinary training for future aircraft designers. Another location, opened also in 2001 in the State of Sao Paulo is the newly developed Gaviao Peixoto plant where the planes for the defence and executive markets are assembled. Neiva's previous facility near the city of Botocatu is the third manufacturing centre in the state. The most important aerospace cluster nevertheless remains Sao Jose dos Campos, home to most of Embraer's suppliers in the lower tiers, many of them spin-off of CTA or Embraer. Apart from the CTA-developed technology commercialized through the establishment of a new company, the streamlining of Embraer's activities resulted in a number of employees creating their own company as service providers on the second or third tier.

The question today is whether Embraer can sustain its growth momentum. The crisis of 2008-09 showed the vulnerability of an industry dependent on regional and executive jets. At the same time the innovation system, which is crucial for to sustain competitiveness, is very much dependent on one single actor, Embraer. The relatively outdated technological capabilities, the lack of sufficient credit lines and venture capital make it difficult for local SMEs to become competitive and join global supply chains as risk sharing partners (ABDI 2009). To boost the competitiveness of local SMEs is a major concern for the government. There is a growing consensus about the need to modernize the education and training system, to support innovativeness through new aircraft development and procurement policies or offset agreements targeting the supplier chain to create a globally competitive centre of excellence in aerospace. In the meantime, the global competitive landscape is changing and new planes need to be even more fuel efficient to reduce operations costs and greenhouse gas emissions. The latest large civilian aircraft designs use composite materials at an unprecedented scale, in which Embraer is lagging behind. The cost share of avionics in a new aircraft has reached unprecedented heights. The aircraft producer that can access these at the best terms will definitely have a competitive advantage. Brazilian companies in these two rapidly growing technology domains have no frontier capabilities to offer for foreign system assemblers.

Currently, the new direct challenges to Embraer's leadership are the financial crisis and its aftermath, and the new players that have made significant advancements in entering the regional jet industry, including Comac in China, the Russian Sukhoi and Mitsubishi in Japan alongside the newest models of the Bombardier C-Series jets, that offer greater efficiency by stronger engines and a higher share of composite materials. From its part, Embraer's response to the financial crisis was diversifying regional jet technology into the defence market. In 2009, the government officially commissioned Embraer to development a military transport and tanker aircraft (the K/C-390) which also enjoys support from prestigious US partners such as Boeing. In 2013, in response to airline demand and the Bombardier C-Series challenge, Embraer also initiated the development of a second generation of the E-Jets, the E2 family, with less radical design change but more efficient engines. Clearly, the competitive pressure is not to relax in the near future.

7. Discussion: the fate of defeated firms

There is of course another side to the story on the evolution of leadership: the stories of former leaders that lost their positions or the stories of unsuccessful others, among them new entrants. Large, experienced companies such as McDonnell Douglas and Boeing in the United States, Airbus in Europe and Tupolev in Russia, or relatively smaller ones such as the Swedish Saab, Dornier (a Daimler Benz company and later Fairchild-Dornier), the French-Italian ATR or IPTN of Indonesia have all considered or tried carving a share of the regional jet market at some point. Why have they not succeeded? Were the preconditions insufficient, were windows of opportunity not open for all, or did they fail in their strategic response?

The explanation lies in the combination of all these factors for each of the above case. In the early 1990s, the preconditions in terms of technological capabilities to design and mass-produce and market a competitive commercial jet were undoubtedly available for McDonnell Douglas (MDD), Boeing and Airbus. However, MDD did not have the investment capacity, and the financially struggling company eventually merged with Boeing. Neither Boeing, nor Airbus saw the need to seize the windows of opportunity and enter the regional jet market, especially not the 50-seat segment, as they considered the regional market more limited and more price-sensitive than the large civil aircraft markets. Both companies addressed the 100-130 seat range with scaled-down version of their larger jets optimized in their design for 150-200 seats. Even if in the 2000s, this market became more lucrative, neither of the aircraft offered proved competitive among regional jets, not even with the benefits of family similarities for network carriers.

The other companies lacked some crucial elements we consider as preconditions. Russian companies inheriting the advanced Soviet technology base had to face brain drain and an erosion of the sectoral innovation system in Russia, and even those that launched new models, such as Tupolev, lacked the know-how to produce cost-efficient, reliable designs. In Indonesia, IPTN, a co-producer and co-designer of turboprop transport aircraft lacked the experience to design, produce and market jets and could not draw on a well-established sectoral innovation system.

European aircraft makers of smaller aircraft struggled in a lethal competition in the 1990s, and the collaboration in the framework of Airbus absorbed significant resources and did not succeed in the regional segment. Even if the necessary threshold technological capabilities were available, the financial capacity of firms and individual host governments was limited and targeted mostly the larger civil aircraft segment. Saab, for instance, already had experience in producing a reliable regional turboprop aircraft as well as fighter jets, but has never combined these technologies into commercial jets which would have needed significant investment. Dornier, as a subsidiary of Fairchild, did show its capability by launching the Do-328JET, a 30-seat jet version of its regional turboprop aircraft Do-328, but the performance and efficiency of the aircraft first delivered in 1999 fell short of that of its overseas competitors, and the loss-making company declared insolvency and could not launch a radically new design.[20] The lack of investment capabilities precluded the company from entering the more promising 70-120 with a new design. Evidently, the window of opportunity for 50-seat regional jets in the 1990s opened at the detriment of the turboprop market. Eventually, only the French-Italian ATR consortium managed to survive the shakeouts in the turboprop market that saw the exit of Saab, BAe and Fokker. With hindsight, European companies have made a wrong strategic response by retaining their own programs and not pooling resources as Bombardier managed to do. There are many explanations why no such European consortium could succeed in the regional jet segment (Heerkens et al, 2010). An important reason for producers' inability to collaborate in new projects was their lock-in in parallel programs initiated in the 1980s that proved less cost-efficient than the rest. Product life-cycle in the industry is long, and sunk costs of initial investments can only be recovered after 300-500 aircraft are sold, thus more than two-three companies have no room in a constrained market.

Sunk costs in development and lock-in with a relatively out-of-date design can be just as important a problem for incumbent leaders as for others. In this sense, both BAe and Fokker became victims of their own success. The design of their 100-seat regional jets and the use of international partners to share the burden were efficient and innovative enough to offer a competitive edge in the 1980s. It appeared to be a logical strategy for the companies to invest the limited amount of capital at hand into their competitive advantage serving a promising enough market, rather than embark on an uncertain venture into making a 50-seat jet. To their misfortune, airline economics made the 50-seat jet market more lucrative in the 1990s, and the Bombardier and Embraer aircraft proved to be disruptive innovations in a niche market (Abernathy and Clark, 1985; Christensen, 1997). As a result, their products, the BAe-146 and the F-100, did not generate sufficient revenues to allow investment of own resources in a substantially new development program, and did not have access to additional, significant government funding. On the contrary, both companies were constantly under pressure to economize their operations and were forced to cut workforce in order to be

[20] Nevertheless, the Do-328JET remains the most significant European competitor in the regional jet market, with 110 aircraft delivered.

profitable.[21] Fokker was the first to be forced out of business in 1996. The takeover by DASA, a company itself struggling with the EF2000 *Eurofighter* programme and the Dornier operations, did not result in solving Fokker's cash-flow problems. With pessimistic outlook for the Fokker product line, neither the Dutch government nor potential Asian investors could save the company from declaring bankruptcy in 1996.

To mitigate the effect of substantial sunk costs in light of changing technological and demand conditions, a viable option for incumbents is to resize or upgrade existing products. Resizing an existing design in order to better meet market demand has its inherent technical limits. For instance, shrinking the BAe-146 and F-70/100 designs to be competitive against Bombardier and Embraer was not feasible. Upgrading, on the other hand, has proved to be good solution for British Aerospace, as it managed to conduct an overhaul of the BAe-146 in the Avro RJ programme in 1993. Major changes included adding new Honeywell engines, all digital avionics and a new cabin, which contributed to improved performance and reduced maintenance costs. This way, the life cycles of the three sizes of the BAe-146 (the -100/200/300) were successfully extended, and 170 additional aircraft were sold under the new designation RJ-70/85/100. But as shown earlier, yet another upgrade of these products based on a thirty-year-old design was not marketable any longer after the turn of the millennium, and BAe Systems chose not to raise funds for a clean-sheet design. With another downturn in the industry looming in the wake of 9/11 2001, BAe Systems announced the cancellation of the RJX programme and eventually ended regional jet production two years later. By this strategic move, the company decided to focus its activities on other segments of the aerospace industry (defence, or supplying the large civil aircraft industry) and BAe Systems has remained one of the largest aerospace firms.

It is also interesting to point out that many of the leadership changes overlapped, at least partly, with economic downturns. The first half of the 1990s saw a down-cycle and a consolidation in the global aerospace industry, but the aftermath of 9/11 also brought a shock to the industry. Mathews (2005) and Lee and Mathews (2012) argued that downturns may provide for favourable timing of entry for challenger firms. In fact, we notice that the relatively less costly regional jets offered airlines increased efficiency in contrast with larger aircraft. This clearly aggravated the problems of the incumbents, and British Aerospace and Fokker struggled to reach the break-even point with their regional jets with lower delivery rates.

[21] Fokker underwent a rationalization programme in 1994-95 and cut workforce by a third to 8,500 workers and managed to reduce production lead time by half. The Avro operations of British Aerospace took even harsher cuts from 7000 to 1950 jobs in assembly and marketing ("Fokker prepares for new round of cuts" *Flight International*, 22-28 Feb 1995).

As for Bombardier, the fate is still to be seen. After long delay and a temporary hold of the programme, the first of the C-Series, designed to compete with Embraer's E-Jets as well as the smaller members of the Boeing B-737 and Airbus A-320 family, completed its maiden flight in 2013 and orders are slowly picking up. The company, after abandoning the idea of a clean-sheet design at the beginning of the 2000s changed its mind and opted for developing a new design, with higher share of composite materials and more efficient engines, claiming significant reduction in operating costs. At this point it is too early to tell how this will affect leadership of Embraer. Unlike BAe, Bombardier's stakes in the aerospace industry are focused on the regional segment. Yet unlike Fokker, Bombardier's product portfolio is diverse enough to help the firm exit the "incumbent trap". Despite the limited room for manoeuvre due to the sunk costs and the lock-in with collaborative ventures, it showed it could marshal a few strategies to maintain a significant market share: apply power to delay competitors (WTO dispute); it effectively resized the CRJ200 to cover a part of the 70/120-seat niche market (up to a hundred seats); it demonstrated organizational flexibility by revisiting the abandoned idea of a clean-sheet design in light of the competitor's success; and finally, it is important to note that the conglomerate can, at least temporarily, generate sufficient revenues from its operations in other transport industries.

In this strategic industry, power appears to be another important tool for incumbents to mitigate the effect of missed windows of opportunity, at least temporarily. Power in this context means the capacity to delay or deter emerging competitors and defend one's market share. It may take different the form of financial power or market power, but the ultimate goal is always to secure a demand window for own benefit, often with the help of a regulatory window. Incumbents with a favourable liquidity position can possess the power to acquire emerging competitor firms. For instance, Bombardier, although hardly an incumbent yet, made the strategic move to acquire Shorts in 1989 once it also announced credible plans to develop a competitor to its CRJ regional jet it was already working on. In contrast, Fokker with its liquidity problem was lacking means to exercise financial power and defend itself against emerging competitors.[22] Incumbents with sufficient power over the supplier or user markets have effective means to delay development or production time of competitors relying on the same component or subsystems suppliers, or enforce regulations (i.e., environmental, safety, etc.) for airlines that favour own aircraft models over those of competitors. Companies that are important players in a national economy can exercise leverage over a wide range of public policies measures. The strategy of granting access to market in return for access to

[22] In fact, the very purchase of Shorts by Bombardier can be seen as a challenge against Fokker as well, since the British company was also producing wings for Fokker which itself had capacity problems.

technology was followed by latecomers such as Brazil in the 1970s and 80s and is followed by China today. Governments typically consider aerospace firms as strategic, and are less hesitant to apply their economic or political weight in their support. A good example is the trade war between Canada and Brazil, initiated by Bombardier following the allegations that the Brazilian government decreased the export price of Embraer jets with illegal subsidies in the framework of PROEX, and leading to retaliatory measures in other trade. Yet such power may be limited, as Embraer and the government of Brazil were successful in raising a counter claim, and eventually as eventually the WTO Dispute Settlement Body found both disputants in breach of international trade law, it had little effect on competitive position of the companies (see Doh, 2003, Goldstein and McGuire, 2004). Providing a full account of all dimensions of power would merit a study of its own, including a closer investigation into the supply chain and the airline market. Here we suffice with the observation that power co-evolves with leading companies and other key actors of aerospace innovation systems.

In sum, it appears that both incumbents and new entrants face substantial uncertainty, attributable more to the price of oil and macro-economic developments than to new technology.[23] Incumbents may find themselves in a crisis if they fail to react at least later to emerging windows of opportunity, but late-reacting new entrants are in an even worse situation due to the long lead time and recovery of sunk costs (see the experience of Shorts, Fairchild Dornier, AVIC, IPTN, etc.).

8. Conclusions: emerging patterns of leadership change

This section summarizes the conclusions from the case studies in order to identify common features of leadership change in the regional jet manufacturing industry. A brief outline of the key sources of leadership change is given in Table 2.

We have observed that leadership changes occurred in a relatively short period of time, and were linked to production cycles of families of regional jets. In the case of BAe, the source of leadership was the 146 family (over 1984-1990), in the case of Fokker, it was the F-100/70 (1990-1995), in the case of Bombardier the CRJ family (the CRJ100/200/700/900 models), between 1995 and 2005, with a short interruption in 2000, in the case of Embraer it

[23] The following quote on Bombardier exemplifies well the situation. "Asked to predict when struggling Bombardier will return to financial strength, chief executive Paul Tellier challenged the questioner: 'Tell me how long it is going to take for the airlines to get back on their feet, where the Canadian dollar will be, where the oil price will be, and I will tell you when.' " ("Paying the price of caution" *Flight International*, 14-20 Dec 2004)

was the E-Jets (E170/190 models), following 2005. The fact that companies were able to act so fast is due to the capabilities that had already existed in the countries.

Without certain **preconditions**, no challenger could gain leadership in the regional jet market. First and foremost, a precondition was technological and investment capabilities within reach for challenger companies, which is hardly surprising considering the high technological and capital intensity of the sector. None of the newly emerging leader companies were new entrants to the sector by the time they set out to challenge the leadership position of the incumbents; they had already a long experience in aircraft manufacturing. In other words, they paid the cost of entry and passed the steep initial learning curve earlier. Crucially, they possessed absorptive capacity to apply for regional jets technology that already existed in other segments of the aerospace industry. They could also draw upon resources available in the innovation system. That is why government support was crucial to create the preconditions for growth, by training scientists and engineers, performing public research and development and providing favourable business environment and access to external finance and technology in all our cases. We note that alongside the support for the innovation system in a given country hosting the headquarters of a challenger firm, these firms could benefit from the active involvement of other governments that hosted a second-tier component supplier. In this way, all four leaders benefitted from US technology. Furthermore, technological and investment capabilities alone are not sufficient for leadership change, unless these were complemented by a sufficiently deep knowledge of the market, which a company could gain from the sales of related products. In the case of BAe and Fokker, it was the experience with a regional-scale, older generation jet (BAC-111 and F-28), for Bombardier it was the experience as a component supplier (Shorts for Fokker) as well as a turboprop commuter producer, in the case of Embraer, its experience with commuter aircraft operating airlines mattered. This also implied an active engagement in after-sales support and maintenance. The resulting in-depth knowledge of the market was crucial for being able to provide appropriate response to new demand, and thus secure sufficient orders to reach the break-even point.

Company leadership in the regional jet industry has been associated with **leading products**. Leading products are aircraft – or aircraft families with a high degree of similarity with one another but seat ranges or engine performance, i.e. the BAe-146-100/200/300 and the Avro RJ70/85/100 – that constitute the backbone for a company's market leadership, or the largest share of their output in terms of number of deliveries. Over the history of the regional jet industry, leading products were addressing different market segments within the sector. The leadership of BAe and Fokker in the 70-100-seat segment rested upon the fortunes of the BAe-146 and the Fokker F-100, Bombardier owed its success in the 40-50-seat market to the CRJ200, and Embraer once again took the leadership in the larger, 70-120-seat segment with the ERJ-170/190 jets as oil prices rose and smaller regional jets could not compete with turboprop any longer.

Whether a family becomes a leading product, depends on the **timing and duration of windows of opportunity**. The long lead time between the development of the concept of a new aircraft and the entry into serial production brings a fair amount of risk to the enterprise. If an innovator launches the development of a new product having read signals that a combination of window of opportunities have opened, but these windows have been closed by the time the new product enters the market, the cost of failure for the company is enormous. Leadership change therefore depends on the favourable condition and timing of windows of opportunity.

First, typically a technological window of opportunity opens in combination with the promise of a demand window, so that the combination of these two should make it favourable for the innovator to launch the development of a new product. However, in order to turn this new product into a leading product, a demand window, often in combination with a window created by changes in the regulatory environment, should be open at the time when the development process is finalized and the new product is to enter into serial production to boost orders and sales.

Leading products do not necessarily have to be radical clean-sheet designs, but improvements of existing models by re-sizing and re-engining, as in the case of the Fokker 100. However, it appears that the chances of remaining in the market after newly emerging windows of opportunity with these kinds of products may be more difficult than with clean-sheet design, as (at least) two-generation-old vintage platforms easily become uncompetitive. In fact, Fokker's design and the company did not survive the 1990s challenge, but BAe's 146 rejuvenated as the Avro jets still generated sales in the 1990s. However, re-engining them as the RJX was not sufficient anymore for the BAe models to survive Embraer's challenge in the 2000s. Similarly, Bombardier stretched and re-engined its new design and succeeded in extending the production cycle until today, although not anymore as a leading product. This proves that product life cycles matter for competitiveness (Klepper, 1996), and companies that fail to already initiate development of a new product family at the declining phase are at risk of exiting the industry. Slow reaction to windows of opportunity in a competitive environment may be worse than no reaction at all. The lead-time in the sector is long, and there is a real risk of windows of opportunity closing by the time the product receives the necessary certifications for sales. Thus a product's life-cycle will not be aligned with the windows of opportunity, and low delivery rates not generate sufficient revenue to reach the break-even point and accumulate capital that can be invested in a new clean-sheet design. There is, of course, an element of luck and foresight ability to be able to judge how long windows of opportunity will be available. These two factors, slow response and erroneous judgement contribute to what can be called the "innovators' trap", which may be the fate of leaders and followers alike, as once a firm has launched a product development, it is locked in due to the investments and established networks.

The timing of windows of opportunity and the successful launch of potentially leading products have a number of policy implications. Along with the questions of "What did governments do to support challengers?", or "What did governments do to ensure that current or past leaders are withstanding challengers?", we also have to ask "When did governments intervene effectively?". First, preconditions for companies to respond to emerging windows of opportunity depend on the performance of the innovation system, on the availability skilled human resources, basic as well as applied research results from public research organizations, and institutions that facilitate interactions. Second, the speed of response depends on the availability of capital for new entrants to develop and launch a new product, a risky activity where direct or indirect public finance has always played a role and where government loans are (up to a third of the development costs) even compatible with international trade law.[24] Third, governments' regulatory measures can modify windows of opportunity, and instruments such as standard setting, certification or operation requirements, or selection of trading partners have in fact been strategically applied. Fourth, at the time when a new product is ready to enter markets, governments have once again a range of tools at hand to create a trade-friendly business environment. Price is a determinant factor of competitiveness of aircraft, where a weaker currency combined with macroeconomic stability can help, however, if that condition is lacking, governments have found a way for export financing by interest-rate equalization mechanisms or export credits. National prestige aside, it is not leadership but innovation-based competitiveness which may be in the best interest of the public, for what it is equally crucial to ensure that interventions, if exist, are temporary.

The source of windows of opportunity was typically external to the incumbent or challenger companies' activities, however, some institutional factors could be influenced by producers with a large enough size and power. In some special cases, windows of opportunity

[24] See i.e. the 1992 EU – US Agreement on Large Civil Aircraft; the applicability of this agreement to regional jets is debated.

were opened with the strategic collaboration of key actors in the innovation systems (leading companies, governments, or airlines), such as the creation of favourable tax conditions, an export financing regime, or the preservation and later relaxation of scope clauses. Yet the effectiveness of such "tinkered" opportunities in the longer term depended on the existence of other windows of opportunity (such as sufficient demand).

Windows of opportunity that entailed favourable market conditions or growing demand for regional jets were in principle open for incumbent as well as challenger companies. Incumbents could often not exploit these as much as newcomers because of the sunk costs in their existing (less competitive) products that have not accumulated a break-even delivery volume. This absorbed substantial financial and engineering resources, thus did not have the capacity to respond to challenges. In a few cases where former leaders could liberate some capacity, they could regain their leading positions – as seen in the case of Fokker coming back after it lost leadership with the F-28 to BAe.

The common pattern in firms' strategic response to windows of opportunity over the past three decades entailed the introduction of technologically superior, produced more efficiently in greater production rates. Thus it was an increasing competition to design aircraft with more cost-efficient operational performance, and to be able to offer greater production capacity. Challengers therefore succeeded by ever more focusing on a core competence (lead design, system assembly, sales and after-sales support activities) which allowed efficiency increase and cost reduction. Their main product innovations were new to the regional jet market but not necessarily new to the world: even the organizational innovations (i.e. risk-sharing partnership model) were already introduced in the large civilian aircraft segment earlier. In this sense, the companies can be considered as "strategic followers" (Mathews, 2005) or those scaling down existing technology within an existing architecture (Christensen, 1997).

One can also notice another historical trend behind leadership dynamics: the duopoly regime of the 1980s (BAe-Fokker) has, after the painful decade of the 1990s, been replaced by another duopoly regime consisting of Bombardier and Embraer. This also corresponds to a change in the industrial organization from a mostly in-house producing and innovating structure to one relying primarily on global supply chains and risk-sharing collaborations with companies specializing in a narrow segment of the value chain. It is interesting to note that the simultaneous presence of a high number of competitors coincided with relatively low fuel price. This could also have implications for the future competition with new entrants such as Comac's ARJ-21, Mitsubishi's MRJ or the Sukhoi *Superjet* (to list only the aircraft that successfully flew) – should, of course, these companies and their host countries have realized all the necessary preconditions and favourable demand windows open in their favour.

Finally, one may wonder how specific these conclusions are to the regional jet industry. Other capital and technology-intensive industries, from other segments of the aircraft industry, to other transport equipment sectors, as well as industries involving complex product systems, where accumulating sufficient technological capabilities are necessary for latecomers to be credible challengers, may arguably follow similar paths. Of course, market conditions differ, and competitiveness has a completely different meaning (if any) in the highly geopolitical military aircraft industry than in the automobile or shipbuilding industry. The large commercial aircraft segment would of course show most similarities in leadership dynamics. Such an analysis would nevertheless require a longer historical and narrower geographical scope: at least in the jet age, an initial British leadership in the 1950s was early on replaced by American companies, only to give way to the recently established Boeing-Airbus duopoly. But the nature of preconditions, of windows of opportunity and of strategic response would be very similar.

Acknowledgement

The author would like to thank the comments and feedback of Keun Lee, Franco Malerba and the participants of the Milan 2012 June and Seoul 2013 May Workshops on Catch-up cycles.

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Table 1 – Technological and market performance of leading regional jets

Manufacturer (family)	Aircraft	RJ Market	Maximum seats	In serial production	Nr. Produced[a]	Maximum range[b] nm (km)	Turbofan Engine Type	Engine bypass ratio	Max. cruise speed Mach (km/h)	Cabin Width (m)
British Aerospace / BAe Systems (BAe-146 fam.)	**BAe-146-100**	70/120-seat	94	1983-1992	35	1,620 nm (3,000 km)	4 x Textron Lycoming ALF 502R	5.7:1	M 0.72 (760 km / h)	3.42 m
	BAe-146-200		112	1983-1993	98	1,600 nm (2,963 km)			M 0.72 (760 km / h)	3.42 m
	BAe-146-300		128	1988-1998	60	1,520 nm (2,817 km)			M 0.72 (760 km / h)	3.42 m
BAe/Avro (RJ70/100 fam.)	**RJ70**		94	1993-1996	12	1,660 nm (3,075 km)	4 x Honeywell LF-507	5.3:1	M 0.73 (788 km/h)	3.42 m
	RJ85		112	1993-2002	87	1,780 nm (3,295 km)			M 0.73 (788 km/h)	3.42 m
	RJ100		118	1999-2002	71	1,780 nm (3,295 km)			M 0.73 (788 km/h)	3.42 m
Fokker (F70/100 fam.)	**F-100**	70/120-seat	122	1988-1996	276	1,450 nm (2,685 km)	2 x Rolls Royce RB.183 Tay	3.04:1	M 0.77 (844 km/h)	3.1 m
	F-70		85	1995-1997	45	1,780 nm (3,295 km)			M 0.77 (844 km/h)	3.1 m
Bombardier (CRJ fam.)	**CRJ200**	50-seat	50	1992-	1,100	1,585 nm (2,936 km)	2 x General Electric CF34-3B	6.2:1	M 0.81 (860 km/h)	2.53 m
	CRJ700	70/120-seat	78	2001-	331	1,504 nm (2,785 km)	2 x General Electric CF34-8C	5:1	M 0.85 (876 km/h)	2.57 m
	CRJ900	70/120-seat	90	2003-	274	1,515 nm (2,806 km)			M 0.83 (885 km/h)	2.57 m
	CRJ1000	70/120-seat	104	2010-	19	1,622 nm (3,004 km)			M 0.82 (870 km/h)	2.57 m
Embraer (E145 fam.)	**ERJ-145**	50-seat	50	1996-	701	2,000 nm (3,706 km)	Rolls-Royce AE 3007-A1	5:1	M 0.78 (830 km/h)	2.10 m
	ERJ-135	30/50-seat	37	1999-	108	1,750 nm (3,243 km)			M 0.78 (830 km/h)	2.10 m
	ERJ-140	30/50-seat	44	2001-	74	1,650 nm (3,058 km)			M 0.78 (830 km/h)	2.10 m
Embraer (E-Jet fam.)	**ERJ-170**	70/120-seat	80	2004-	178	2,100 nm (3,889 km)	2 x General Electric CF34-8E	5:1	M 0.82 (870 km/h)	2.74 m
	ERJ-175	70/120-seat	88	2005-	143	2,000 nm (3,706 km)			M 0.82 (870 km/h)	2.74 m
	ERJ-190	70/120-seat	114	2005-	386	2,400 nm (4,448 km)	2 x General Electric CF34-10E	5:1	M 0.82 (870 km/h)	2.74 m
	ERJ-195	70/120-seat	122	2006-	88	2,200 nm (4,077 km)			M 0.82 (870 km/h)	2.74 m

Source: Own compilation based on manufacturers' website, airliners.net and flightglobal.com
Notes: (a) Nr. produced by Dec 2011; commercial variants only, figures exclude business, cargo and defense derivatives; (b) for long range variants

Table 2 – Key drivers of leadership change: preconditions, windows of opportunity and leading products

	Window of Opportunity			New Leader	
Preconditions	**Technology**	**Demand**	**Regulatory**	**(other challengers – type of design[a])**	**Leading product**
Bombardier's leadership in the 50-seat RJ market					
• Advanced Canadian aerospace innovation system; • Bombardier predecessor companies' capabilities	• more efficient engine (5:1 bypass ratio)	• US: hub-and-spoke system; competition of hubs; congestion • EUR: liberalization, integration • Low oil prices • preference for jets over turboprops	• Scope clauses capping 50-seat market	• Bombardier – Rad. • (Embraer – Rad.) • (Dornier – Incr.) • (Shorts – Rad.)	• Bombardier CRJ200 and CRJ family, leader in 50-90 seat market
Embraer's leadership in the 70-120 seat RJ market					
• Brazilian aerospace innovation system; • Embraer's privatization and experience in commutes and regional jets	• improvements in engines, avionics, materials; as well as in aviation infrastructure	• increasing oil prices, • replacement of aging narrow-body jets • fluctuations in world economy	• scope clauses relaxed; • environmental regulations	• Embraer – Rad. • (BAe – Incr.) • (Boeing – Incr.) • (Airbus – Incr.) • (Bombardier – Incr.)	• Embraer "E-Jet" family (ERJ-170/190), leader in 90-120 seat market

Note: a) Type of design: Incr. = incremental improvements in existing design; Rad. = radically new clean-sheet design

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